FRICTION CRACKS AS DIRECTIONAL INDICATORS OF GLACIAL FLOW ON MT. DESERT ISLAND, MAINE[1]

ROBERT D. SLOCUM[2], Department of Botany, The Ohio State University, Columbus, OH 43210

Abstract. A detailed study of friction cracks from a Late Pleistocene glacial pavement on the southeastern corner of Mt. Desert Island, Maine, has shown that these small scale glacial erosion features may be used as reliable indicators of the direction of glacial flow. Directional information suggests that ice flows in response to micro- and macrotopography in a limited area. Direction of concavity for a given type of friction crack is constant, but concavity is a useful tool in determining the direction of ice flow only if one distinguishes between crescentic gouges (concave upstream with respect to glacial flow) and both lunate fractures and crescentic fractures (concave downstream). In non-schistose rock types, the most consistent friction crack parameter is primary fracture dip, which is downstream in the direction of ice movement.

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Friction cracks are small-scale glacial erosion features commonly found in association with striae and grooves on bedrock protrusions. Numerous authors have reported these crescent-shaped marks on glacial pavements in various parts of the world. The use of friction cracks as indicators of the direction of glacial flow has been discussed for many years, but there is still some controversy over the interpretation of directional data obtained from field studies. Establishment of criteria for the use of friction cracks as directional indicators is important because 1) friction cracks, unlike striae or grooves, are unidirectional indicators 2) friction cracks are well-preserved, even on severely weathered pavements and 3) these marks are commonly found in glaciated areas.

Friction cracks appear most frequently on the stoss sides of roches moutonnées (LaHee 1912; Dreimanis 1953) in glaciated areas and range in size from a few centimeters to several meters in length (DeLaski 1864; Virkkala 1951). These crescent-shaped marks lie with their long axes transverse to the general direction of ice flow and occur characteristically in sets. Friction cracks are widespread on Late Pleistocene glacial pavements and have been observed on a variety of rock types (Harris 1943; LaVerdiere *et al* 1968b). The oldest known marks are from a Late Paleozoic pavement (Hamilton and Krinsley 1967).

The formation of friction cracks is generally attributed to a buildup of differential friction between a bedrock surface and debris carried in the overriding glacial ice, and the subsequent release of stresses set up within the underlying rock through fracture. The various types of friction cracks (fig. 1) have been described and categorized (Chamberlin 1888; Ljungner 1930; Harris 1943) as crescentic gouges, lunate fractures and crescentic fractures. A more recent classification of friction cracks including variations of these types has been proposed by LaVerdiere *et al* (1968a). All friction cracks share a common characteristic, a distinct fracture dipping forward into the rock, with respect to glacial flow. A crescentic marking often described in friction crack studies is the "chattermark" (Chamberlin 1888), which possesses no true fracture, and thus should not be classified as a friction crack. In addition, p-forms (channels, bowls, sickle-troughs) have also been included in discussions of friction cracks, but these

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[2]Present address: Department of Botany, The University of Texas, Austin, TX 78712.

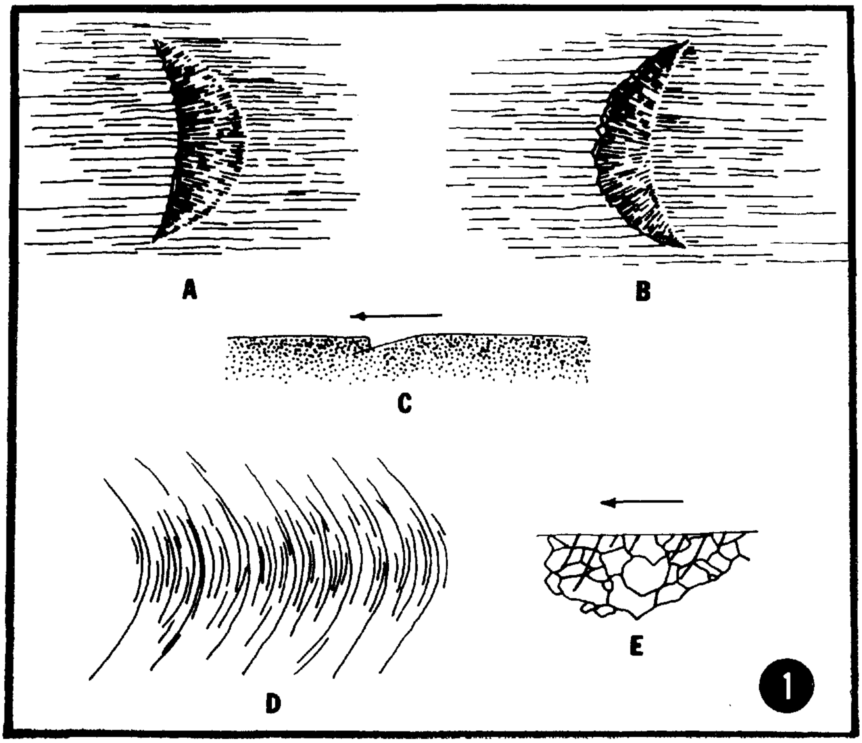


FIGURE 1. Three main types of friction cracks. The lunate fracture (A) and crescentic gouge (B), both exhibiting a secondary vertical fracture terminating against the primary oblique fracture, which dips forward into the rock (C). Crescentic fractures (D) consist of single cracks dipping forward into the rock (E). Arrows mark the direction of ice flow. (A, B and C after Harris 1943; D and E after LaHee 1912).

features have probably been misinterpreted as the result of direct abrasion of ice and debris (Bernard 1971).

Probably the first reference to friction cracks in the literature was by DeLaski (1864), who described "lunoid furrows" (crescentic gouges) on granite around the Penobscot Bay area in Maine. Several authors had reported friction cracks and related phenomena by the turn of the century (Packard 1868; Hitchcock 1876; Winchell 1877; Chamberlin 1888; Russell 1889; Salisbury 1902). While these early papers dealt primarily with the physical characteristics of the marks, the potential use of friction cracks as directional indicators of glacial movement was also examined. Andrews (1883) suggested that grooves with their associated (fraction) cracks, horns pointing forward in the direction of ice movement, could be used to determine the direction of glacial flow in a given area. DeLaski (1864), however, had noted the concavity of friction cracks to vary both with and against the supposed direction of flow, and Chamberlin (1888) proposed that concavity alone was not a reliable directional indicator. Differences in concavity, he suggested, might be explained by different modes of formation, as with his "crescentic cross-features" (crescentic fractures).

Later workers' multifarious conclusions concerning concavity of friction cracks and the direction of ice flow (Daly 1902; Gilbert 1905; LaHee 1912) led Harris (1943) to propose the use of the forward-dipping oblique fracture as a more reliable directional indicator. He observed this fracture to dip dowstream, regardless of the direction of concavity. Friction cracks with dips against the presumed direction of ice flow (Dreimanis 1953; Flint 1955; Rocha-Campos *et al* 1969) have been reported, leading some workers to believe that neither concavity nor fracture dip could be used as a directional indicator. Dreimanis (1953) observed, however, that schistocity of the rock may influence fracture dip. In granite and other non-schistose rock types, a downstream primary fracture dip has been consistently reported (Daly 1902; Gilbert 1905; LaHee 1912; Harris 1943; Okko 1950; Dreimanis 1953; Guimont 1972), hence it would appear that direction of primary fracture dip in non-schistose rock can be used with certainty to infer the direction of ice movement.

PHYSICAL SETTING AND EVIDENCES OF GLACIATION

In the summer of 1974, a classic example of friction cracks, occurring both singly and in sets, was discovered on a relatively recent glacial pavement situated on the stoss side of the *The Beehive*, a typical roche mountonnée landform lo-

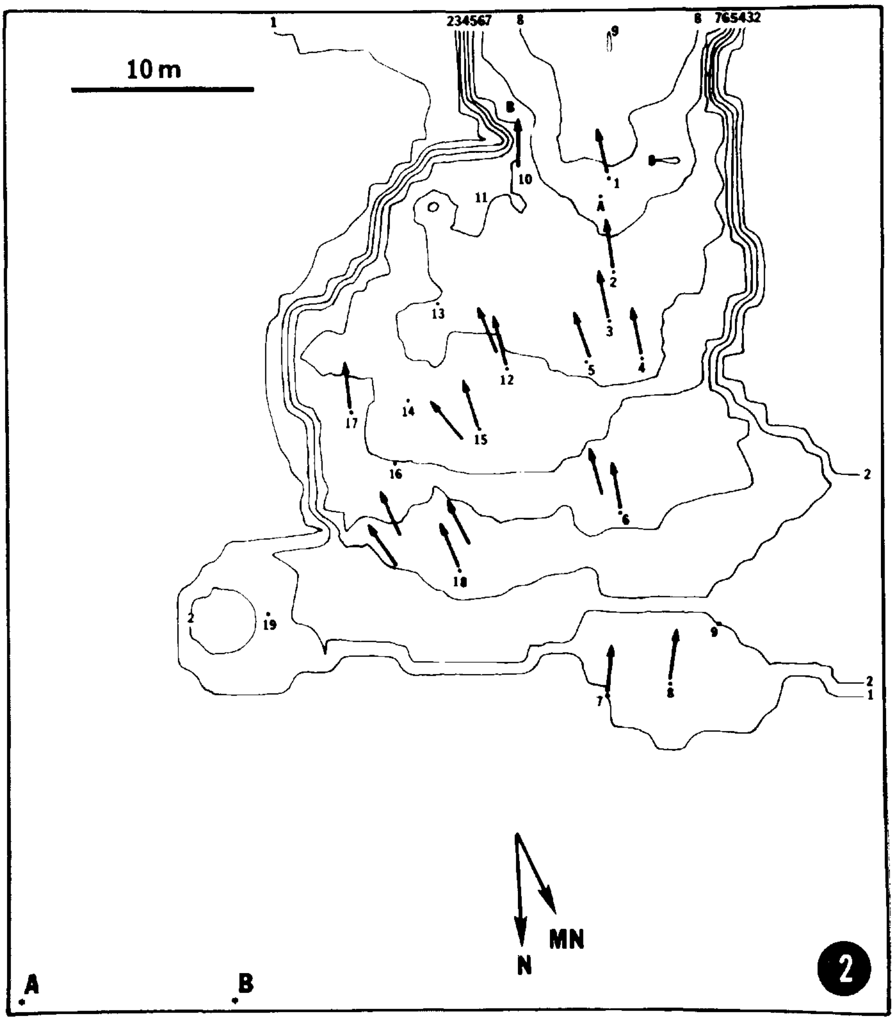


FIGURE 2. Computer map of the study area based on survey data derived from 21 points (Note base stations A and B). Friction cracks indicate the direction of ice flow over the granite outcrop. Arrows represent longitudinal axes of sets or single, prominent friction cracks. Contour intervals = .305 m (1 foot). True north (N) and magnetic north (MN) are indicated.

cated on the southeastern corner of Mt. Desert Island, Maine (44° 20N, 68° 11W). The site is a large (approximately 1000m^2), gently-sloping (10–40°) outcrop of coarse-grained orthoclase feldspar granite, the most resistant lithology formation on the island, and friction cracks are well-preserved. The extensive north-south Wisconsin ice flow across the study area is evidenced by characteristic U-shaped glacial valleys and stoss-lee topography. Grooves, striae, friction cracks and polishing depict the small-scale glacial scouring of the area. Block-faulting and plucking on the downstream sides of projecting granite bosses provided the tools for glacial abrasion, and nearly all exposed surfaces are blanketed with till, a large percentage of which is composed of erratics (Chapman (1962).

METHODS

The entire granite outcrop comprising the study area was surveyed in order to establish the exact locations of glacial marks and to allow the accurate plotting of directional information with respect to surface topography. Survey data, based on 21 reference points marking prominent sets of friction cracks and other surface features, were obtained using a DKM-2 theodolite and then run through a series of computer programs, producing the contour map seen in figure 2. Theodolite error of less than ±5″ was considered acceptable.

Friction crack azimuths were recorded with a Brunton compass to within ±5° and corrected for magnetic declination (N19.5°W). Azimuths of individual friction cracks within a set varied slightly. The azimuth of the set was taken as the average for all members, as each set was interpreted as a single event with respect to glacier flow.

RESULTS AND DISCUSSION

Friction cracks were abundant on the granite outcrops located within the study area. The azimuths of 151 friction cracks were recorded as shown in figure 3. Azimuths vary considerably, probably due to differences in ice flow near the edges of the outcrop; fully 78% of the friction cracks, however, were oriented between S20°E and S10°W, in close correlation with the known approximate north-south movement of Wisconsin ice in the area.

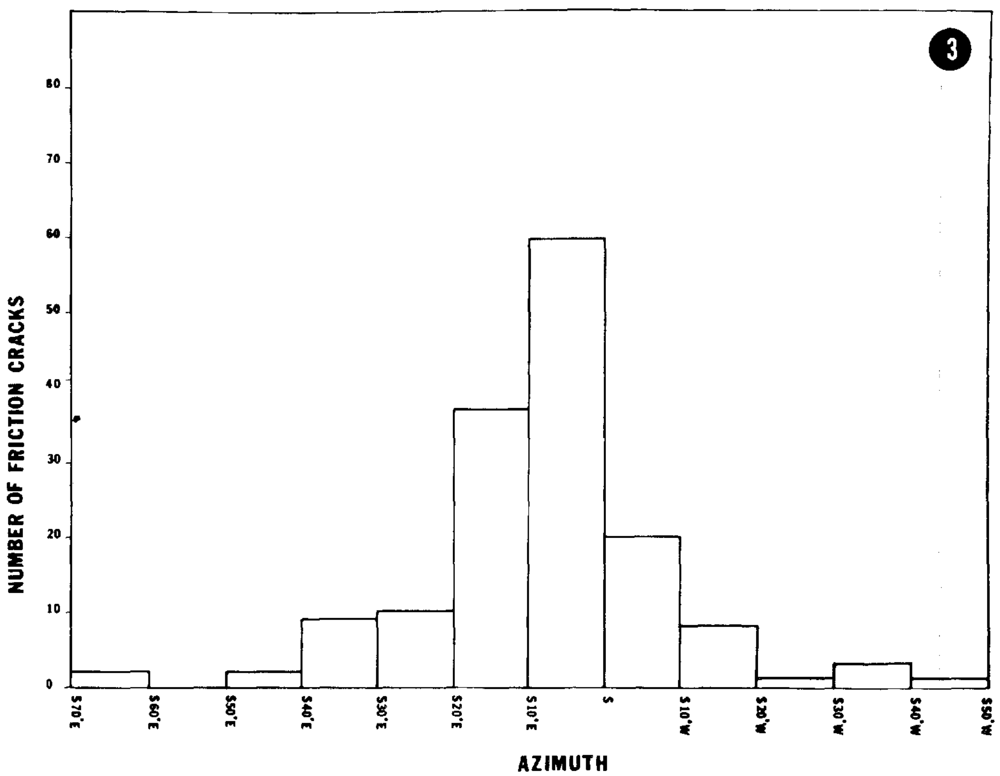
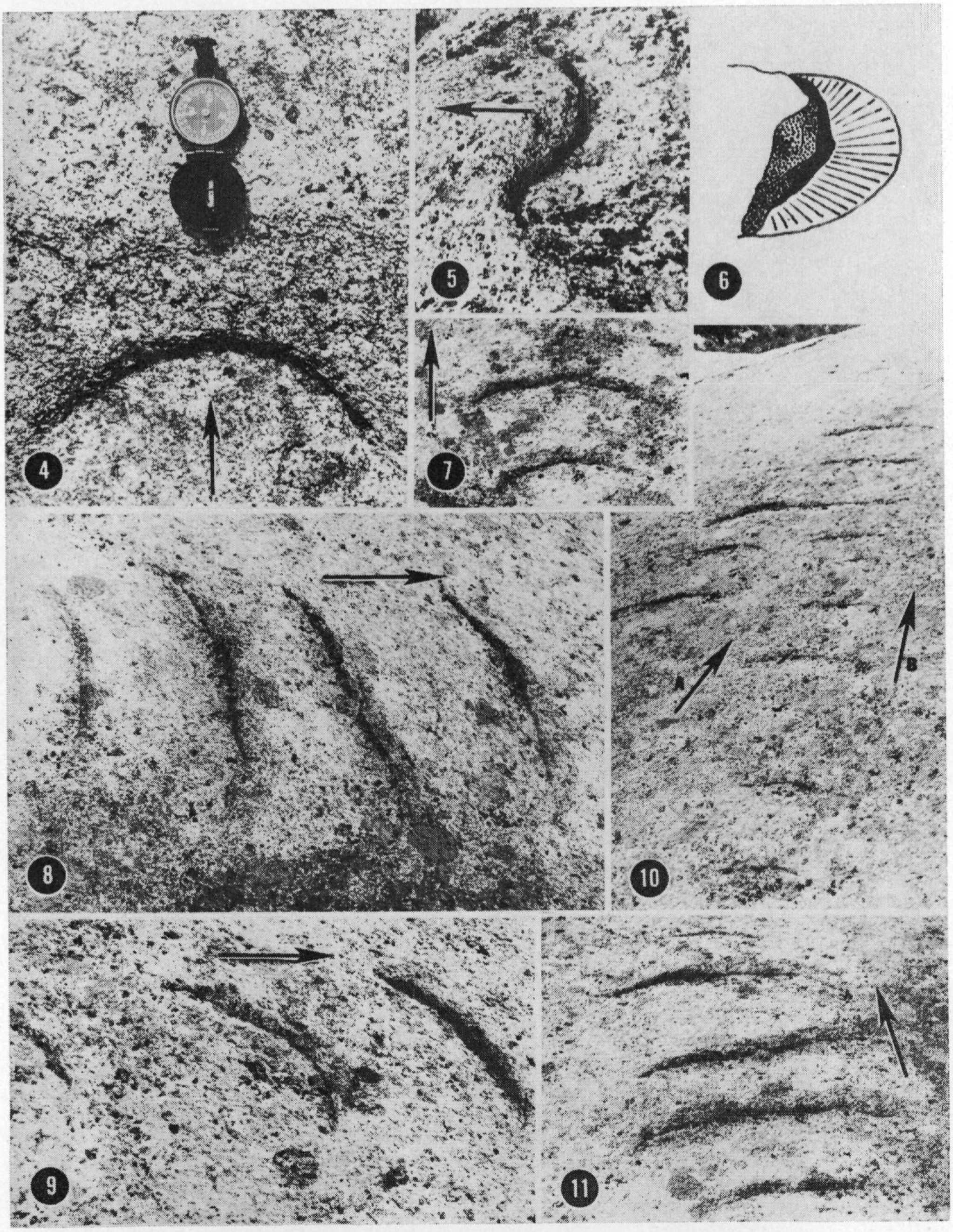


FIGURE 3. Number of friction cracks with main axis azimuths falling with 10° intervals.



FIGURES 4–11. (Arrows indicate direction of glacial flow.)

FIGURE 4. Crescentic gouge showing downstream primary oblique fracture (arrow) and secondary vertical fracture (crescent-shaped). Brunton compass used to record azimuth.

FIGURE 5. Lunate fracture formed upstream from small granite projection. Note downstream concavity.

EXPLANATION CONTINUED ON PAGE 16

FIGURE 6. Line drawing of Figure 5.

FIGURE 7. Set of crescentic gouges showing increased size of downstream gouge.

FIGURE 8. Face view of set of crescentic gouges. Note irregular secondary fractures.

FIGURE 9. Face view of crescentic gouge set. Note regular vertical (secondary) fractures and increased size of downstream gouges.

FIGURE 10. Set of crescentic gouges illustrating apparent side-slipping of glacial ice. Arrow A marks direction of mass ice flow to the south. Arrow B indicates orientation of this set to the south-southeast. Edge of vertical wall is seen at top of photograph.

FIGURE 11. Face view along longitudinal axis of set of crescentic gouges seen in Figure 8. Note steep inclination of primary fracture into the rock and resulting high vertical fracture walls.

Single lunate fractures (figs. 5 and 6) were occasionally observed, concave sides oriented toward the direction of ice flow. Primary fracture dips of these marks, like those of crescentic gouges, were downstream, further supporting the observations of Harris (1943) and others. Interestingly, lunate fractures were not seen on relatively flat expanses of rock, but frequently were located at the edges of verticle side walls or on the upstream sides of small projecting knobs of granite, in which case, they resembled a simple conchoidal fracture with the rock fragment incompletely removed.

Crescentic fractures were not observed in the coarse-grained granite of the study area, but were noted a short distance away on fine-grained granite outcrops. Concavity and primary fracture dip were downstream in the direction of the ice movement, as previously reported. Crescentic gouges were the most frequently encountered crescentic markings, occurring singly and in sets of 4 to 10. In all cases, the primary fracture dip of these gouges was downstream, supporting earlier studies for non-schistose rock types. Primary oblique fractures were smooth and regular; secondary vertical fractures were sometimes regular (figs. 4 and 9), but more often rough and irregular, giving the marks an assymetrical appearance (fig. 8). Concavity of crescentic gouges was invariably upstream, against the direction of flow. In general, the size of these marks appearing in sets increased in a downstream direction (figs. 7, 10 and 11).

Ice flow lines across the entire study area were accurately reconstructed from directional data obtained from friction crack azimuths (fig. 2). Contours plotted on the computer printout agree closely with observed microtopography of the outcrop. Flow lines oriented towards the south-southwest (points 7 and 8) are undoubtedly the result of ice being channeled in the observed direction by 2 steep-walled outcrops just upstream from this location. Most of the ice flowed approximately north-south across the face, although the influence of the vertical wall on the east side of the outcrop apparently altered the direction of local ice flow to the south-southeast as seen at points 15, 16, 18. (An exception is point 17, which is closest to the east wall, but more closely aligned with the overall direction of glacial movement.)

Evidence for a side-slipping of glacial ice near the vertical wall is seen in figure 10. Overall movement of ice in this area is due south (arrow A), as determined from the azimuths of individual crescentic gouges within the sets, however, the orientation of one set (arrow B) is in a south-south easterly direction, possibly the resultant vector of ice flowing over the eastern wall and mass glacier flow to the south. Such evidence is particularly interesting as it suggests that glacial ice flow responds to microtopographic changes as well as more pronounced large-scale topographic features. Information of this type may contribute to our ultimate understanding of the nature of ice flow around obstacles.

Fracture dip was shown to be the most reliable directional indicator in the present investigation from a non-schistose rock type. The effects of schistocity on the initiation and dip of the primary fracture of friction cracks has been little-studied, however, and should be further investigated. Local topography may influence the orientation of ice flowlines, and thus friction crack azimuths, to some degree. This factor must be considered in the evaluation of directional data and numerous glacial pavements should be examined in any locality. Fraction cracks with azimuths deviating even as much as 50° from the median were rare, however, and in no instance did altered ice flow produce crescentic markings with primary fracture dips against the direction of ice flow.

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LITERATURE CITED

Andrews, E. 1883 Glacial markings of unusual forms in the Laurentian Hills. Amer. J. Sci. 26: 101–102.

Bernard, C. 1971 Les marques sous-glaciaires d'aspect plastique sur la roche en place (p-forms): observations sur la bordure du bouclier canadien et examen de la question (1). Rev. Geogr. Montreal 25: 111–127.

Chamberlin, T. C. 1888 The rock-scourings of the great ice invasions. U.S.G.S. 7th Ann. Rept., pp. 218–223; 247–248.

Chapman, C. A. 1962 The Geology of Acadia National Park. Eastern Press, Inc., New Haven, 128 p.

Daly, R. A. 1902 Geology of the northeastern coast of Labrador. Bull. Mus. Comp. Zool. (Harvard) 38: 240–245.

DeLaski, J. 1864 Glacial action about Penobscot Bay. Amer. J. Sci. 37: 337.

Dreimanis, A. 1953 Studies of friction cracks along the shores of Cirrus Lake and Kasakokwog Lake, Ontario. Amer. J. Sci. 251: 769–783.

Flint, R. F. 1955 Pleistocene geology of eastern South Dakota, U.S. Geol. Surv. Prof. Paper #262, p. 58–59.

Gilbert, G. K. 1905 Crescentic gouges on glaciated surfaces. Bull. Geol. Soc. Amer. 17: 303–316.

Guimont, P. 1972. Broutures glaciaires sur gres de Potsdam, St. Hermas, Québec. Rev. Geogr. Montreal 26: 202–206.

Hamilton, W. and D. Krinsley 1967 Upper Paleozoic glacial deposits of South Africa and southern Australia. Bull. Geol. Soc. Amer. 78: 785.

Harris, S. J., Jr. 1943 Friction cracks and the direction of glacial movement. J. Geol. 51: 244–258.

Hitchcock, C. H. 1876 Existence of glacial action upon the summit of Mt. Washington. Amer. Assoc. Adv. Sci. Proc. 24: 92–96.

LeHee, F. H. 1912 Crescentic fractures of glacial origin. Amer. J. Sci. 33: 41–44.

LaVerdiere, C., C. Bernard and J.-C. Dionne 1968a Les types de broutures glaciaires (glacial chattermarks) 1. Classification et nomenclature franco-anglaise. Rev. Geogr. Montreal 22: 21–33.

—— 1968b Les types de broutures glaciaires (glacial chattermarks) 2. Observations effectuées au Québec. Rev. Geogr. Montreal 22: 159–173.

Ljungner, E. 1930 Spatentektonik und Morphologie der schwedischen Skagerrack-Kuste. Univ. Uppsala, Bull. Geol. Inst. 21: 285–290.

Okko, V. 1950 Friction cracks in Finland. Bull. Comm. Geol. (Finland) 150: 45–50.

Packard, A. S. 1868 Ice marks and ancient glaciers in the White Mountains. Amer. Nat. 1: 265.

Rocha-Campos, A. C., S. Farjallat and R. Yoshida 1969 Crescentic marks on a Late Paleozoic glacial pavement in southeastern Brazil. Bull. Geol. Soc. Amer. 80: 1123–1126.

Russell, I. C. 1889 Quaterny history of Mono Valley, California. U.S. Geol. Surv. 8th Ann. Rept., p. 366–367.

Salisbury, R. D. 1902 The glacial geology of New Jersey. *In:* Glacial Geology, Vol. 5, Trenton. Geological Survey of New Jersey. Final Rept. of the State Geologist, p. 538–539.

Virkkala, K. 1951 Glacial geology of the Suomussalm Area, East Finland. Bull. Comm. Geol. (Finland) 155: 17.

Winchell, N. H. 1877 Geology and Natural history survey of Minnesota, 6th Ann. Rept., p. 106–107.